DETERMINATION OF THE RATIO OF THE PROBABILITIES FOR ELECTRON CAPTURE AND POSITRON DECAY OF Sb^{115} *WITH THE AID OF A SCINTILLATION GAMMA SPECTROMETER*

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A simple method is suggested for determining the ratio of the probabilities of electron capture and positron decay for the case when the spectrum of the investigated isotope contains a γ line with energy $\sim m_0c^2$. The method is used to determine the value of ϵ/β^+ for the 32-minute positron-active isotope Sb^{115} under the assumption that positron decay occurs at the 499-keV excited level of the daughter nucleus Sn^{115}. The value obtained, $\epsilon/\beta^+ = 1.99$, is in satisfactory agreement with the theoretical value (~ 1.87). Special attention is paid to the exact determination of the areas under the total absorption peaks, which are very important in calculations of the above-mentioned ratio by the method suggested here. The procedure can be realized in practice with no difficulty and does not require intensity calibration of the spectrometer.

In order to establish the decay schemes of positron-active nuclei, it is important to know the ratio of the electron-capture and positron-emmission probabilities ϵ and β^+. The expressions for the probabilities of transitions with electron capture and with positron emission include unknown nuclear matrix elements. Consequently, measurements of the decay energy and of the half-lives cannot be compared directly with the theoretical transition probabilities. However, if the electron capture and the positron decay occur between identical nuclear states, the nuclear matrix elements are also equal. The probability ratio ϵ/β^+ will therefore not depend on the nuclear matrix elements, making it possible to check with the aid of the experimentally measured ratio the theory of β decay, independently of the knowledge of the nuclear matrix elements and wave functions.

The aforementioned probability ratio can be determined by absolute measurements of the number of x-ray quanta and positrons, by comparison of the number of Auger electrons and positrons in a magnetic spectrometer, and in special cases by using a coincidence procedure. Frequently the value of ϵ/β^+ is obtained by comparing the x-ray and annihilation radiation intensities with a scintillation gamma spectrometer.

Of definite interest is the case when the daughter nucleus is produced as a result of electron capture and β^+ transition in a state whose excitation energy is equal to or close to the energy of the annihilation photons (511 keV). The transition of the nucleus from this state into the ground state can be accompanied by the emission of γ quanta, which give exactly the same picture of spectral distribution as the annihilation photons. Owing to the low resolving power of the scintillation gamma spectrometer ($\sim 10\%$), it is impossible to separate in such cases by simple means the annihilation line from the gamma line, which, in turn, makes it difficult to determine ϵ/β^+ by comparing the x-ray and annihilation radiation intensities.

An example is the 32-minute positron-active isotope Sb^{115} ($E_\gamma = 499$ keV), which we investigated recently. The decay scheme of Sb^{115}, taken from an earlier work[1], is shown in Fig. 1. According

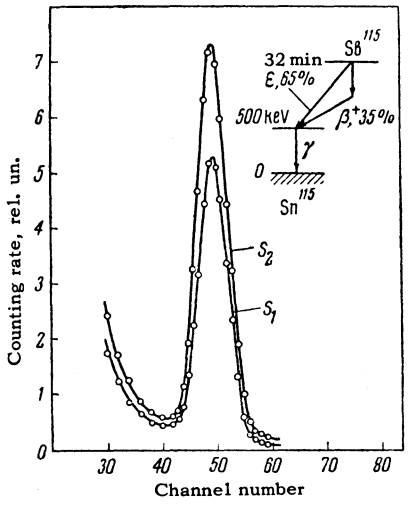

FIG. 1. Decay scheme and γ spectra of Sb^{115} taken with one (S_1) and two (S_2) lead plates.

to this scheme, the nucleus Sb^{115} goes over by means of electron capture and positron decay into the excited level 499 keV of the daughter nucleus Sn^{115}. The limit of the β^+ spectrum and the energy of the gamma line, measured with a double-lens magnetic beta spectrometer, have respective values 1510 ± 20 and 499 ± 2 keV. The scintillation gamma spectrometer showed an intense x-radiation, indicating electron capture of high probability with a half life of 32 minutes. The fact that the gamma spectrometer was not calibrated with respect to intensity and that the 499-keV line was under the peak of the annihilation radiation did not enable us to determine the ratio ϵ/β^+ experimentally.

We have previously proposed a simple method for separating the gamma line from under the peak of annihilation radiation, wherein it is possible to determine simultaneously the electron capture to positron decay probability ratio at the 499-keV level of the daughter nucleus Sn^{115}[2]. The method is simple and does not call for intensity calibration of the scintillation spectrometer. The gist of the method consists in the following. A thin layer of the investigated compound is deposited on a metal substrate sufficiently thick to absorb all the positrons emitted in a solid angle 2π. The area S_1 under the total absorption peak corresponding to the annihilation radiation is measured. Then an analogous metal plate is placed directly on top of the source and the area S_2 under the annihilation peak is again measured. If the total absorption peak is due only to annihilation radiation, then the following relation will hold true

$$S_2/S_1 = 2\,(1 - \chi), \qquad (1)$$

where χ — coefficient of backward scattering of β^+ particles from the substrate material in the angle 2π[3]. It is easy to see that if the spectrum contains a gamma line with $E_\gamma \sim m_0c^2$, relation (1) changes into

$$S_2/S_1 < 2/(1 - \chi).$$

Thus, by measuring the ratio S_2/S_1 by this method, it is possible to conclude that the gamma spectrum contains lines with energy close to or equal to m_0c^2. The area under this line is calculated from the formula

$$S_\gamma = [2S_1 - S_2\,(1 - \chi)]/(1 + \chi).$$

With the aid of the foregoing method we have determined the ratio of the probabilities of electron capture and positron decay for the radioactive isotope Sb^{115}. According to the decay scheme given in Fig. 1, the quantity ϵ/β^+ can be determined from the ratio

$$\varepsilon/\beta^+ = [3 - (2 - \chi)\,D]/(D - 1), \qquad (2)$$

where D denotes the experimentally determined value of the ratio S_2/S_1. The results of our measurements are shown in Fig. 1.

The radioactive isotope Sb^{115} was obtained by irradiating an enriched foil in a cyclotron, using deuterons with energy ~ 11 MeV, in accordance with the reaction $Sn^{114}(d, n)Sb^{115}$. The antimony was separated from the tin chemically. The absence of annihilation radiation from other activities was verified by measuring the half-life. Following the chemical separation from the tin, the radioactive Sb^{115} was deposited on a lead plate 1 mm thick. In calculating the areas S_1 and S_2, a correction for the radioactive decay was introduced. The value coefficient χ of backward scattering from lead was taken for β^+ particles from the paper of Seliger[4] and amounted to 0.5.

As is seen from (4), the ratio ϵ/β^+ is very sensitive to the value of D. To obtain satisfactory results it was therefore necessary to determine with good accuracy the areas S_1 and S_2. To this end we processed the photopeak by the method proposed by Zimmermann[5], which consists in linearization of the Gaussian distribution. It is known[6,7] that the line shape in a scintillation gamma spectrometer is described quite well by a Gaussian distribution

$$g\,(n) = \frac{S}{\sigma\sqrt{2\pi}} \exp\left\{-\frac{(n - n_0)^2}{2\sigma^2}\right\}. \qquad (3)$$

Here n_0 is the number of the analyzer channel corresponding to the maximum intensity of the total absorption peak, S is the area under the curve, and σ is the mean-square deviation of n from its mean value n_0.

Using the property of the Gaussian curve

$$g\,(n - 1)/g\,(n + 1) = \exp\{2\,(n - n_0)\,\sigma^{-2}\} = q\,(n),$$

we can write the following obvious formula

$$\ln q\,(n) = 2\sigma^{-2}\,(n - n_0).$$

A plot of ln q(n) is a straight line with a slope that determines with good accuracy the value of $2\sigma^{-2}$. Once σ is determined, the area under the total absorption peak can be calculated with the aid of the following expression:

$$S = \sigma\sqrt{2\pi}\,g\,(n) \exp\{(n - n_0)^2/2\sigma^2\}. \qquad (4)$$

Figure 2 shows linearized plots of the total absorption peak, which we obtained using one and two lead plates (Fig. 1). We determined from these

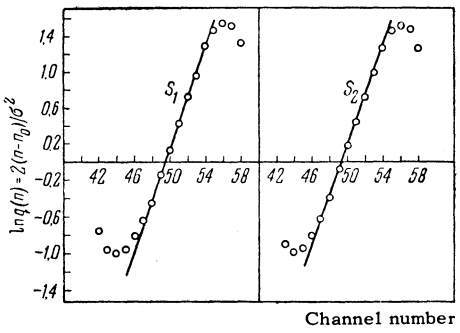

FIG. 2. Linearized plots of the total absorption peaks shown in Fig. 1.

plots the values of n_0 and σ, from which we calculated with the aid of (4) the areas S_1 and S_2. A value 1.43 was obtained for the ratio $S_2/S_1 = D$. If we assume that the decay scheme of [1] is correct, then the results of our measurements yield for ϵ/β^+ a value 1.99, which agrees well with the theoretical value 1.87 [8,9]. Such a result confirms once more that the experimentally obtained values of ϵ/β^+ for allowed transitions agree with theory within several per cent [10,11].

In conclusion, the author expresses his gratitude to Yu. A. Ryukhin for chemical separation and preparation of the thin source, and also P. S. Samoĭlov for a discussion and for interest in the work.

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